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CARBON NANOTUBE BASED MICROFLUIDIC ELEMENTS FOR FILTRATION AND CONCENTRATION

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ABSTRACT

We have developed a method for integration of patterned arrays of carbon nanotubes or the “nanotube mesh” into microfabricated channels. The method includes standard lithographic methods for patterning and etching the substrate, followed by catalyst patterning, CVD deposition of nanotubes, and anodic bonding of coverslip top. We will describe a carbon nanotube filtering device fabricated using this method and discuss the use of carbon nanotube arrays as molecular concentration and separation media.

KEYWORDS

filtration, concentration

INTRODUCTION

Filtration of the sample prior to processing is an essential step when performing analysis in microfluidic devices. Since microfluidic channels are small, particle contamination can cause operational problems. On chip filtration methods are desirable because they allow handling of small amounts of liquid, which could not be processed via conventional filtration methods and are sufficient for analytical on-chip processing. Concentration of the analyte is another essential step that increases detection efficiency. Carbon nanotube microfluidic elements have a potential for both filtration and concentration.

A common approach for microfluidic filtering has been creation of pillar structures or flow restrictions [1, 2]. The limitation of these methods is the resolution of the patterning technique employed. Filtration of sub-micron particles using lithographically patterned structures would require expensive fabrication methods such as e-beam lithography. Alternatively, emulsion photopolymerization has been used to create filters of various pore sizes but this method also creates pores on the order of a micron[3]. Nano-scale filters with pore sizes as small as 10nm have been made using sacrificial layer technology [4].

Carbon nanotubes, with their unique properties, dimensions and a huge surface to volume ratio, have a great potential as a filtration, separation and concentration medium for various chromatographic applications. Carbon nanotube mesh self assembles into a robust nano-porous structure, which eliminates the need for nano-lithographically patterned features. The mesh has pores on the order of 10-50nm, the surface-to-volume ratio superior to the packed bead columns and the surface that can be modified with polymers that incorporate particular chemical functionality [5]. A possibility of patterning carbon nanotube arrays in specific parts of a microfabricated device allows easy integration into microfluidic devices and gives this approach a great advantage over more conventional separation media that requires column packing such as silica beads. Nanotube arrays can also be tuned to a particular application since it is possible to control nanotube size, density and orientation in the growth process.

METHODS

We use standard fabrication techniques to pattern a 5 nm thick film of iron catalyst in the desired area of the channel etched in silicon. Afterwards we used CVD growth technique to grow carbon nanotube arrays, ranging from 5 μm to 100 μm in height. The catalyst is first oxidized to form islands on which individual nanotubes start to grow. We then use pyrolysis of a mixture of ethylene, hydrogen and argon at 850C which results in a mesh of nanotubes. After we grow the mesh, we seal the devices by anodically bonding a top layer onto them in vacuum. For filtration purposes, we grow the mesh of nanotubes so that it is a few microns taller than the depth of the channel. We rely on good elastic properties of the nanotube mesh and pack all of the tubes into the channel in order to assure that there is no gap between the glass and the nanotubes. Figure 1 shows carbon nanotubes grown in a silicon channel.

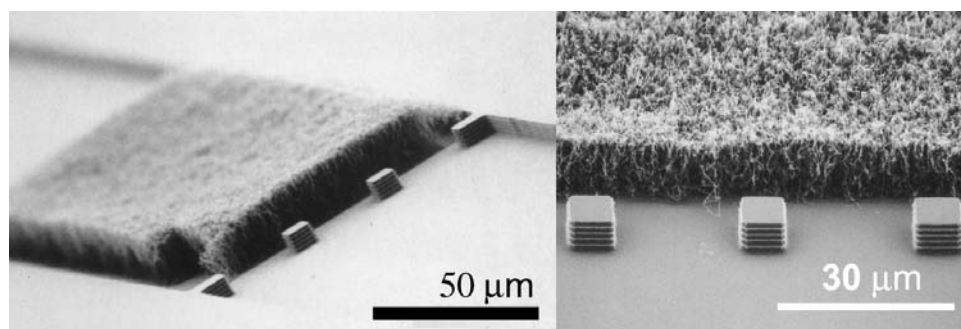


Figure 1: SEM images of the carbon nanotube mesh inside the microfabricated channels in silicon.

RESULTS

In order to demonstrate filtering capability of nanotube elements we used a mixture of fluorescent beads that was moved through the channel using pressure driven flow. Figure 2 shows the fluorescent beads of 198nm diameter concentrated at the carbon nanotube filter. Beads were successfully released from the filter by applying the back-pressure. The solutions contained TWEEN-20 (Sigma) in order to render carbon nanotube surface hydrophilic and facilitate introduction of water into the filter through capillary action. With filter lengths of several hundreds of microns, pressures on the order of a few to a few tens of psi were sufficient to drive the fluid. Since nanotube patches that are only a few tens of microns long should be sufficient for filtering, we do not anticipate the filter impedance to be a practical difficulty. Studies are currently performed to quantitatively characterize the hydrodynamic resistance of the filters as well as to determine the minimum size of the particle that can be filtered in our devices.

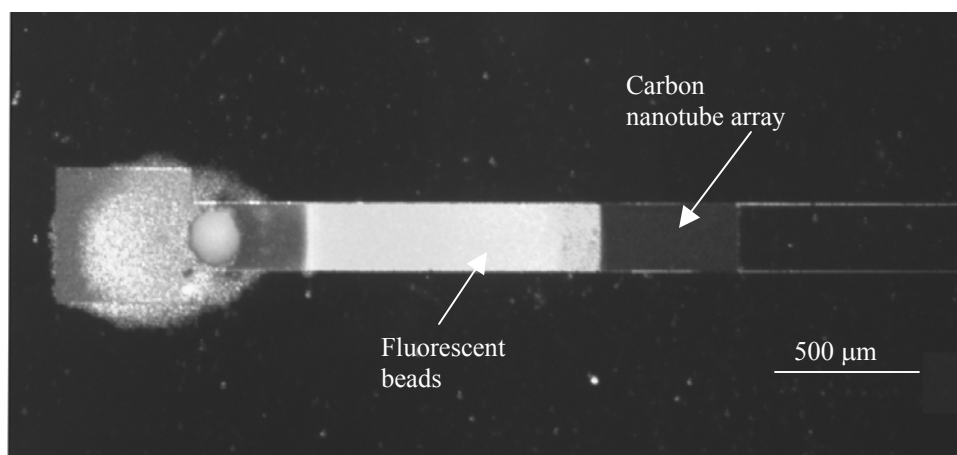


Figure 2 Fluorescent beads ($D=198\text{nm}$) concentrated at the carbon nanotube filter. This channel is $6.5\text{ }\mu\text{m}$ deep. Fluid flow was left to right.

DISCUSSION AND CONCLUSION

We have demonstrated the filtering capability of the carbon nanotube arrays and demonstrated a simple method for integration of sub-micron filters into microfluidic devices. In addition, we are exploring use of these devices and of microfluidic channels with carbon nanotube coating as pre-concentrators for micro-gas chromatography and as

liquid chromatography columns. We are also performing adhesion measurements between various chemical functionalities and the curved graphite-like nanotube surface using chemical force microscopy. A combination of these measurements with *ab-initio* modeling will allow us to understand the molecular interactions with the nanotube surfaces and apply rational design to nanotube based chromatography systems.

ACKNOWLEDGEMENTS

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